MASTER OF SCIENCE
IN
AERONAUTICAL ENGINEERING

INVESTIGATION INTO THE TUMBLING CHARACTERISTICS OF THE TIER III MINUS UNMANNED AIR VEHICLE (UAV)

Robert B Caldwell Jr.-Lieutenant Commander, United States Navy
B.S.A.E., Auburn University, 1986
Master of Science in Aeronautical Engineering-March 1998
Advisor: Richard M. Howard, Department of Aeronautics and Astronautics
Second Reader: Russell W. Duren, Department of Aeronautics and Astronautics

A free-to-pitch wind tunnel analysis of a 1/25-scale model of the Tier III Minus DarkStar Unmanned Aerial Vehicle (UAV) was conducted to better quantify the susceptibility of the aircraft to entering a potentially catastrophic autorotative pitching motion known as tumbling. The objective of the experimental portion of the study was to determine total and dynamic moment coefficients as well as pitch damping coefficients for incorporation into a three-degree-of-freedom computer simulation. The simulation, based on the experimentally-obtained data, revealed that the Tier III Minus would tumble with the proper initial conditions of high angle of attack and/or pitch rate. Also investigated were the effects of uncommanded control surface deflection and wind shear. The simulation revealed a tendency to enter a tumble for control deflections of between -5 and -15 degrees. The results of the wind shear simulation revealed a resistance to tumbling for encountering FAR Part *25* design gusts of 38 and 66 ft/s.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Tier III Minus, Unmanned Aerial Vehicle, UAV, Tumbling

DESIGN OF DIGITAL CONTROL ALGORITHMS FOR UNMANNED AIR VEHICLES

Steven J. Froncillo-Lieutenant Commander, United States Navy
B.S., University of Rhode Island, 1983
Master of Science in Aeronautical Engineering-March 1998
Advisor: Isaac I. Kaminer, Department of Aeronautics and Astronautics
Second Reader: Russell W. Duren, Department of Aeronautics and Astronautics

Recent advances in the design of high performance aircraft, such as fly-by-wire controls, complex autopilot systems, and unstable platforms for greater maneuverability, are all possible due to the use of digital control systems. With the aid of modern control tools and techniques based on state-space methods, the aerospace engineer has the ability to design a dynamic aircraft model, verify its accuracy, and design and implement the controller within a matter of a few months. This work examines the digital control design process utilizing a Rapid Prototyping System developed at the Naval Postgraduate School. The entire design process is presented, from design of the controller to implementation and flight test on an Unmanned Air Vehicle (UAV).

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Unmanned Aerial Vehicles, Rapid Prototyping Systems, Hardware-in-the-Loop Simulation, AROD, FROG, MATRIX, SystemBuild

---

UNMANNED AIR VEHICLES: A STUDY OF RECUPERATED-CYCLE GAS TURBINE APPLICATION

Michael Louis Jensen-Lieutenant, United States Navy
B.S.C.S., United States Naval Academy, 1990
Master of Science in Aeronautical Engineering-March 1998
Advisor: Raymond P. Shreeve, Department of Aeronautics and Astronautics Engineering
Second Reader: Garth V. Hobson, Department of Aeronautics and Astronautics Engineering

The DoD's Unmanned Air Vehicle (UAV) medium and high altitude/endurance programs require reliable and fuel-efficient propulsion systems, which suggests the use of turboprop technology. Operational UAVs use commercial reciprocating engines or high-bypass turbofan engines. Current engine types were reviewed and the potential performance of the gas-turbine cycle with recuperation, which would improve thermal efficiency and specific fuel consumption, was examined. The recuperated cycle was noted to have particular advantages for smaller engines. A study was performed using the GasTurb and GECAT engine codes, using component level efficiencies appropriate for small-scale turbomachinery and heat exchangers, to estimate the potential performance of a recuperated turboshaft/turboprop-powered UAV system in comparison to the present reciprocating engine system. It was shown that the use of a recuperated turboprop in a *Predator-type* UAV would result in extended range, increased power availability, and an altitude capability in excess of those attainable currently with spark-ignition engines. Such a recuperative gas-turbine engine would also provide better reliability than the reciprocating engines currently used by UAV platforms.

DoD KEY TECHNOLOGY AREA: Aerospace Propulsion and Power

KEYWORDS: UAV, Propulsion, Gasturb, GECAT, NEPP, Turboprop, Turboshaft, Recuperation

ACOUSTICAL EMISSION SOURCE LOCATION IN THIN RODS THROUGH WAVELET DETAIL CROSS CORRELATION

Joseph G. Jerauld-Lieutenant Commander, United States Navy
B.S., California Polytechnic State University at San Luis Obispo, 1986
Master of Science in Aeronautical Engineering, Naval Postgraduate School, 1997
Aeronautical and Astronautical Engineer-March 1998
Advisor: Edward M. Wu, Department of Aeronautics and Astronautics
Second Reader: Russell W. Duren, Department of Aeronautics and Astronautics

Flaws in structural elements release strain energy in the form of stress waves that can be detected through acoustical emission techniques. The transient nature of a stress wave is analytically inconsistent to Fourier Transforms, and the wave characteristics under the effects of dispersion and attenuation deviate from the formal basis of the Windowed Fourier Transform. The transient solid body elastic waves contain multiple wave types and frequency components which lend themselves to the time and frequency characteristics of Wavelet Analysis. Software implementation now enables the exploration of the Wavelet Transform to identify the time of arrival of stress wave signals for source location in homogeneous and composite materials. This investigation quantifies the accuracy and resolution of two existing source location methods and develops a third technique using the Discrete Wavelet Transform on a windowed portion of the stress wave signal. A refined method for the spatial location of material damage induced stress waves can be used to directly monitor the safe-life of structures and provide a quantitative measure for the risk assessment of critical and aging structures.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Space Vehicles, Materials, Processes, and Structures

KEYWORDS: Acoustical Emission, Composites, Structures, Wavelet Analysis

APPLICATIONS OF RAPID PROTOTYPING TO THE DESIGN AND TESTING OF UNMANNED AIR VEHICLE (UAV) FLIGHT CONTROL SYSTEMS

John A. Komlosy Ill-Lieutenant Commander, United States Navy
B.A.E., Georgia Institute of Technology, 1985
Master of Science in Aeronautical Engineering-March 1998
Advisor: Isaac I. Kaminer, Department of Aeronautics and Astronautics
Second Reader: Russell W. Duren, Department of Aeronautics and Astronautics

The modern engineer has a myriad of new tools to assist in the design and implementation of ever increasingly complex control systems. A promising emerging technology is rapid prototyping. By totally integrating the development process, a Rapid Prototyping System (RPS) takes the designer from initial concept to testing on actual hardware in a systematic, logical sequence. At the Naval Postgraduate School (NPS), the concept of rapid prototyping has been applied to the discipline of flight control.

The NPS RPS consists of a commercially available rapid prototyping software suite and open architecture hardware to permit the greatest possible range of control and navigation projects. The RPS is crucial in that it allows students to participate in projects from the initial concept to the flight-testing phase of the design process. This thesis describes in detail two of these projects: the development of an Airspeed Controller using the RPS tools and the integration of a Voice Control System developed by ViA, Inc., of Northfield, Minnesota. Both projects demonstrate the inherent flexibility and risk reduction of the rapid prototyping approach to system design.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Rapid Prototyping, Unmanned Air Vehicles, Flight Control Systems

DEVELOPMENT OF GRAPHICAL USER INTERFACE (GUI) FOR JOINT ARMY/NAVY ROTORCRAFT ANALYSIS AND DESIGN (JANRAD) SOFTWARE

Chris F. Lapacik-Lieutenant Commander, United States Navy
B.S.A.E, West Virginia University, 1984
Master of Science in Aeronautical Engineering-March 1998
Advisors: E. Roberts Wood, Department of Aeronautics and Astronautics
Robert L. King, Department of Aeronautics and Astronautics

A Graphical User Interface (GUI) was developed and implemented as the front end of the NPS software Joint Army/Navy Rotorcraft Analysis and Design (JANRAD). The original JANRAD computer program was developed to aid in the analysis of helicopter rotor performance, stability and control, and rotor dynamics. An interactive program, JANRAD was capable of accurately and quickly solving helicopter design problems at the preliminary design level. The addition of the GUI greatly simplified the use of the program but added considerable complexity to the original MATLAB® M-File code. Because of the increased complexity, only the Performance Analysis module of the program was modified. The use of several new features of MATLAB® version 5.1, such as the GUIDE® and Structure functions, simplified the construction of the GUI environment and enhanced the tie between the user interface and performance calculation routines. Although initiated from the MATLAB® command line, the program can now be worked entirely from the "Windows" environment. The performance routines were modified extensively to connect the user input with the existing analysis routines. However, the fundamental method of analysis remains unchanged. Several cases of Sikorsky UH-60A Black Hawk input data were run and results compared with those from JANRAD version 3.1 (1995). The results correlated exactly. A Users Guide was developed and is included in Appendix A.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software

KEYWORDS: Helicopter, Graphical User Interface, Performance, Preliminary Design

JOINT STANDOFF WEAPON CAPTIVE AIR TRAINING MISSILE STEERING COMMAND ANALYSIS FOR THE CARRIAGE AIRCRAFT

Michael E. Overs-Lieutenant Commander, United States Navy
B.S.I.E., West Virginia University, 1982
Master of Science in Aeronautical Engineering-March 1998
Advisor: Isaac I. Kaminer, Department of Aeronautics and Astronautics
Second Reader: Richard M. Howard Department of Aeronautics and Astronautics

A student/faculty team at the Naval Postgraduate School's Department of Aeronautics and Astronautics is continuing work on developing solutions to functional requirements of the Unitary Joint Standoff Weapon (JSOW) Captive Air Training Missile (CATM). Previous work involved development of JSOW to aircraft interface guidance and control system models and algorithms to display realistic weapon fight profile data to the pilot of the CATM aircraft during computer simulation. Modeling tools utilized were XMATH/Systembuild and Designer's Workbench (DWB) software. This thesis involved updating the aircraft model, and integrating a joystick controller to "fly" the CATM aircraft in the computer simulation. Finally, simulation computer results analysis coupled with a pilot survey were used as input to recommendations for possible implementation of the developed displays for production CATM.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Computing and Software, Conventional Weapons, Modeling and Simulation

KEYWORDS: JSOW CATM Steering Commands, Display Animation, Hardware/Software Integration, Pilot Control, Testing of Display Animation

INTEGRATION OF A MULTI-RATE POSITION FILTER IN THE NAVIGATION SYSTEM OF AN UNMANNED AERIAL VEHICLE (UAV) FOR PRECISE NAVIGATION IN THE LOCAL TANGENT PLANE (LTP)

Robert C. Perry-Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1985
Master of Science in Aeronautical Engineering-March 1998
Advisor: Isaac I. Kaminer, Department of Aeronautics and Astronautics
Second Reader: Russell W. Duren, Department of Aeronautics and Astronautics

Differential Global Positioning System (DGPS) provides highly accurate position information but at update rates of one Hz which is inadequate for precise aircraft terminal maneuvering such as take-off and landing. During this period between updates an accurate position estimate in Local Tangent Plane (LTP) can be made using complementary filtering of the DGPS position and indicated airspeed. Use of indicated airspeed as the filter velocity input necessitates the transformation from body to inertial (LTP) reference frame using Euler angle information available from the Inertial Measuring Unit (IMU) or DGPS. This filter provides accurate estimates of both vehicle position and existing wind. These filter outputs of position and wind can then be used as inputs to a trajectory controller to ultimately enable autonomous launch and recovery of an Unmanned Aerial Vehicle.

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Differential Global Positioning System, Unmanned Aerial Vehicles, Inertial Measuring Unit, Euler Angles, Complementary Filter

LASER DOPPLER VELOCIMETRY IN THE SPACE-SHUTTLE MAIN ENGINE HIGH-PRESSURE FUEL TURBOPUMP

James D. Southward-Commander, United States Navy
B.S., University of New Mexico, 1980
Master of Science in Aeronautical Engineering-March 1998
Advisor: Garth V. Hobson, Department of Aeronautics and Astronautics
Second Reader: Raymond P. Shreeve, Department of Aeronautics and Astronautics

Modifications were made to the Naval Postgraduate School cold-flow turbine test rig to enable integration of a two-component laser-doppler velocimetry (LDV) system. The test turbine was the Space-Shuttle Main Engine, High-Pressure Fuel Turbopump, Alternate-Turbopump Development Model, manufactured by Pratt & Whitney. Flow field measurements were obtained, using the LDV system, in the first-stage rotor end-wall region of the test turbine, at three axial locations and at three depths from the end wall. For each survey location, velocity ratios, absolute flow angle, turbulence intensities, and correlation coefficients were examined. The laser data exhibited distinct trends with axial position, depth from the end wall, and with circumferential position. In addition to the laser data, velocity profiles were determined at the first-stage stator inlet and rotor exit planes, using a three-hole pressure probe. Both laser and probe data were taken at referred rotational speeds in the range 4815 to 4853 rpm. Phase-locked measurements were recorded using a once-per-revolution signal from a magnetic pick-up as a trigger. TSI Phase-resolved software version 2.06 was used for laser data acquisition and reduction.

DoD KEY TECHNOLOGY AREAS: Aerospace Propulsion and Power, Space Vehicles

KEYWORDS: Turbine, Data Acquisition, Laser Doppler Velocimetry, Space Shuttle Main Engine, High Pressure Fuel Turbopump